Folded optical design for high fidelity atmospheric emulation with a spatial light modulator

SPIE.

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INTRODUCTION

Atmospheric emulators made with spatial light modulators (SLMs) offer the ability to test a laser communication component's performance while in the laboratory with a broad range of turbulence levels[1-13]. We have designed, built, and verified[12] an SLM based arbitrary light field generator (ALF-G) at C-band wavelengths with a folded layout shown in Figure 1. This system is capable of recreating multi-layer turbulence with high fidelity up to D/r0 = 50[12]. This work focuses on the ALF-G's optical design choices, recent improvements, and practical implementation recommendations.

OPTICAL DESIGN: KEY FEATURES

- **SLM C-band pixel response time-** Normally near 250 ms limiting refresh rate to ~2 Hz, well below typical Greenwood frequencies.

SLM-based systems can be used in a static fashion to evaluate components and systems statistically.

- **Number of SLM pixels-** Determines the spatial resolution after reduced by the active area defined by the hologram. Example: SLM provides 1200 pixels, after hologram applied that used 70% of diameter output beam is 840 pixels.

Complex amplitude phase holograms are used to achieve control of the intensity and phase with a phase only SLM[13].

- **Number of SLM phase levels-** The phase front resolution is determined by the number of phase levels each pixel can impart. Complex amplitude phase hologram method reduces phase range [-1.84,1.84]. Example: 1024 SLM phase levels are reduced to 600.
- **SLM Reflective backplane-** Curvature can be compensated with holograms to reduce wavefront error. See Figure 2.
- **SLM Mount-** Center rotation and translation, independent of other optics, avoids translating the beam off-axis of downstream optics.
- **Image Relay and Spatial Filter-** A 4f system filters diffraction orders and relays the field created at the SLM plane to an accessible output plane. We found cage mounts allow ease of alignment and stability.
- **Folding Optic-** Using a pellicle eliminates glass cube beam splitter reflections and reduces collimator reflections by 25%. See Figure 3.

Reflections can be blocked by the slit with SLM alignment.

- **Slit-width-** Set to $w = f\lambda/p$, where p is hologram grating period. This blocks the other diffraction orders while allowing the maximum number of spatial frequencies.
- **Input light source-** Intensity variation in the beam incident on the SLM is carried over to the output. To increase uniformity, we used a long focal length collimator that overfills the active SLM area. Resulted in wavefront error (WFE): PtV ~.38λ and RMS λ\40.

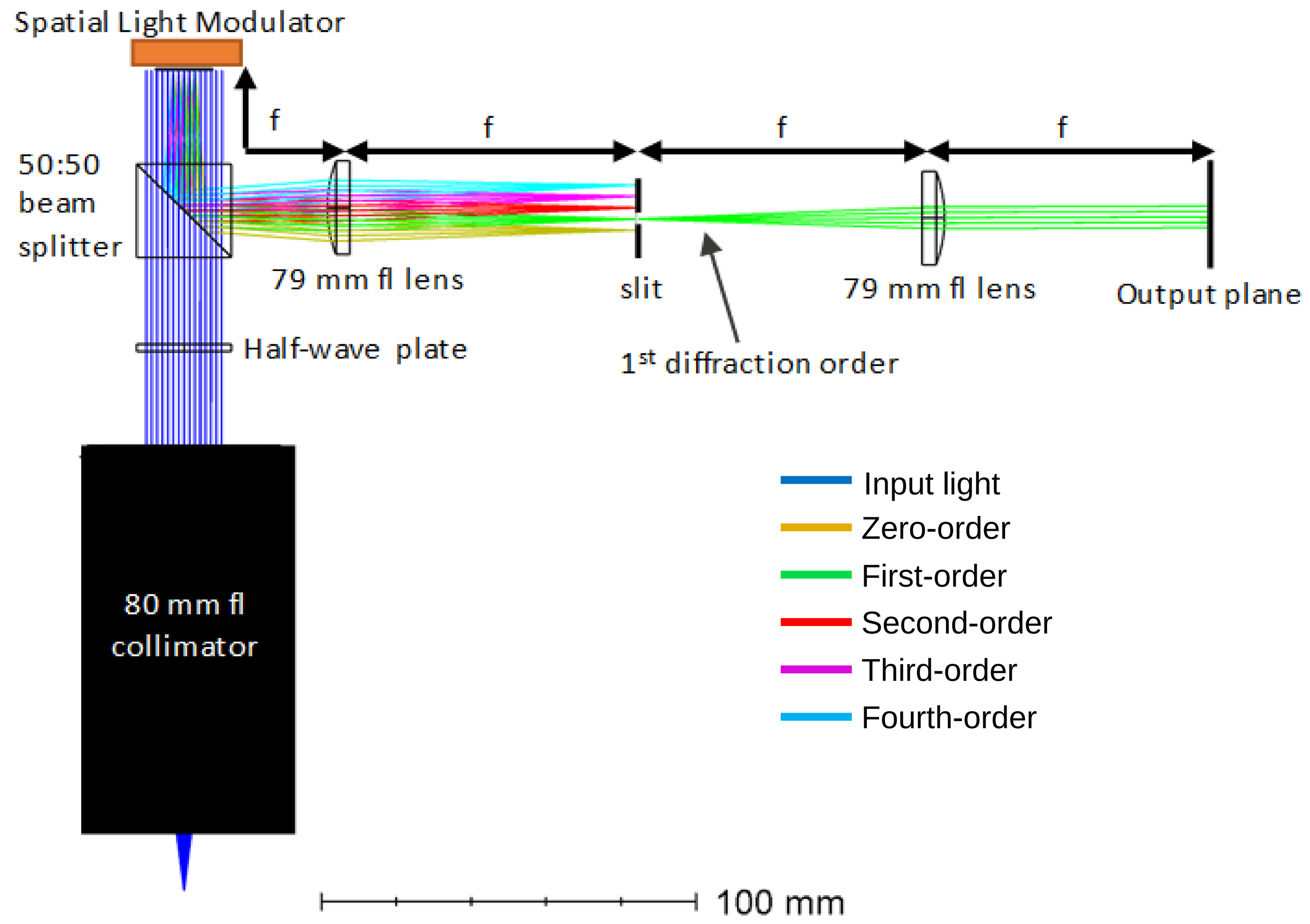

Figure 1. Folded optical layout and ray trace of an arbitrary light field generator (ALF-G).

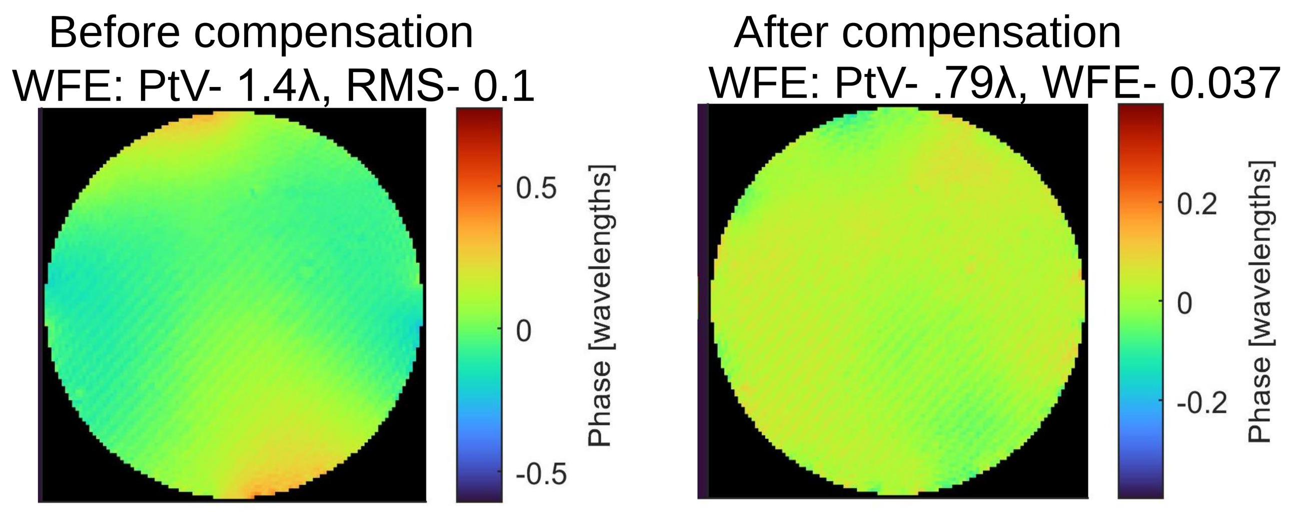

Figure 2. Phase of an applied flat-top beam hologram to an ALF-G built with a curved backplane SLM collected at the output plane.

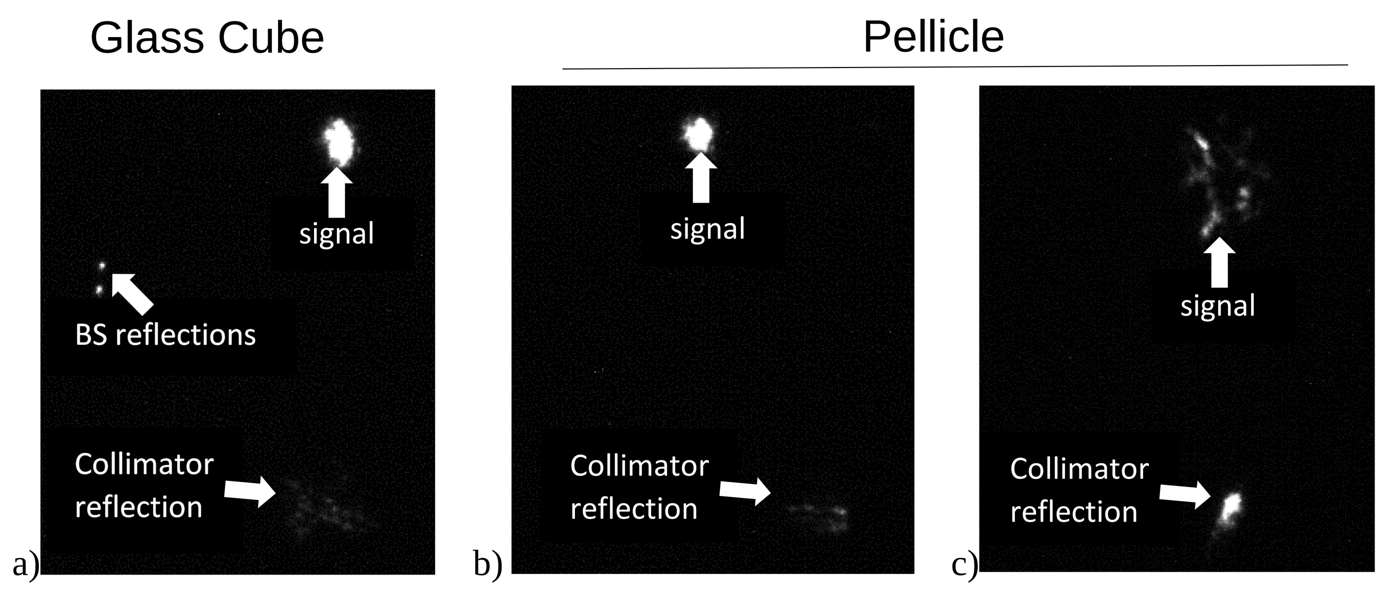

Figure 3. Images of ALF-G signal and unwanted reflections. a) and b) are collected of at the focus of a 100 mm lens placed at the image plane. c) is an image collected at the focus of the collimator reflection.

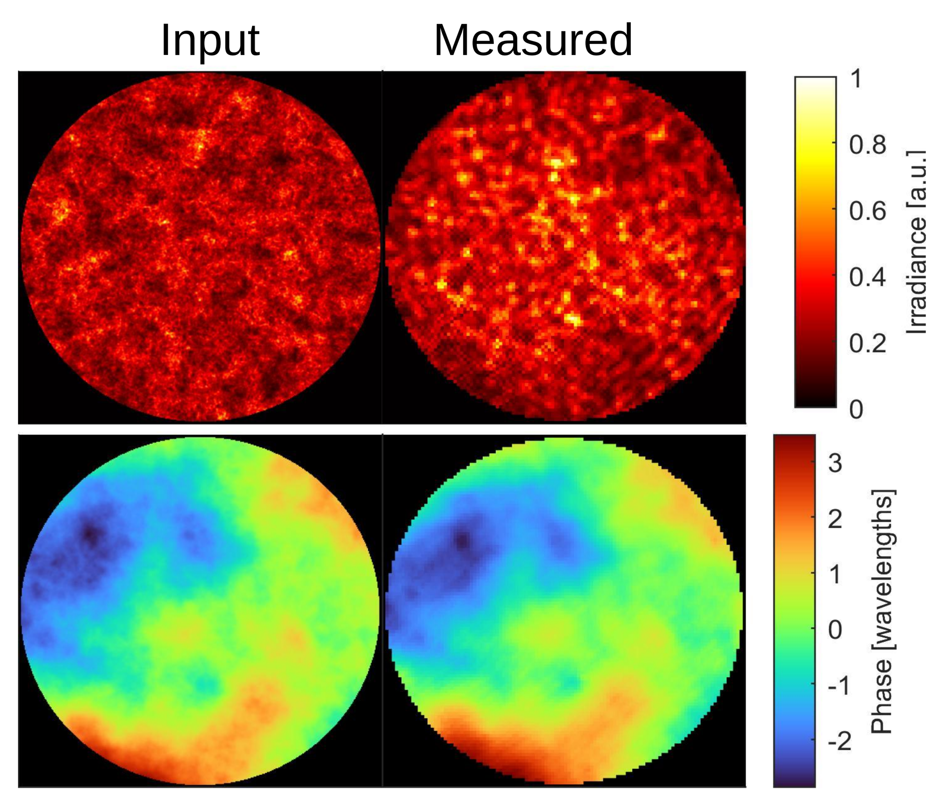

Figure 4. Input of the irradiance and phase compared to the measured output of a beam simulating optical turbulence with D/r0 = 20.

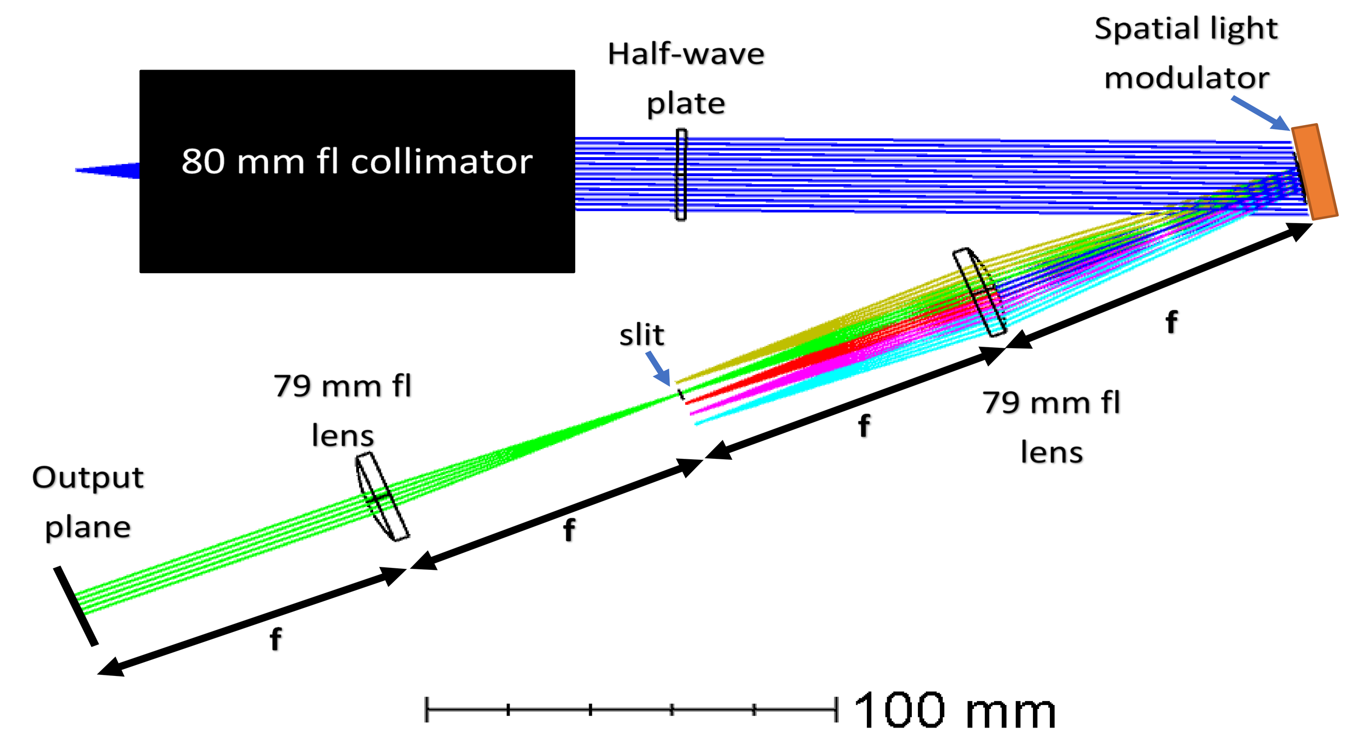

Figure 5. Angled optical layout and ray trace of an ALF-G.

ALTERNATE OPTICAL LAYOUT

An angled optical layout (Figure 5) has the following differences from the folded layout:

- Eliminates the beam splitter → ~75% increased throughput.
- Eliminates all reflections.
- Narrower, longer footprint.
- Optics must be oriented and aligned at an acute angle.

CONCLUSIONS

Optical component specification recommendations:

- Select an SLM with high spatial resolution.
- Overfill the SLM with a long focal length collimator.
- Set the slit at half the dist. between the diffraction orders
- Use a pellicle beam splitter.

Our optical mechanical recommendations:

- Mount the SLM on a rotational and translational mount
- Mount the 4f system to the BS with a cage system.

Future work will include the build and testing of a C-band ALF-G capable of real time emulation of Greenwood frequencies in the hundreds of hertz using SLM's newly on the market in the last few years[14,15]. These new systems may allow the SLM method to overcome its main drawback when compared to rotating phase plates. Complimentary future work will include using wave front sensor measurements of atmospheric data to turn this higher speed ALF-G into a playback system.

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